Dynamics of nitrogen and phosphorus concentrations of fine roots in a mixed forest of *Cunninghamia lanceolata* and *Tsoongiodendron odorum*

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Abstract: From September 1999 to July 2000, N and P concentrations of fine roots were measured with the method of sequential soil core at bimonthly intervals in a mixed forest of Tsoong's tree (*Tsoongiodendron odorum* Chun) and Chinese fir (*Cunninghamia lanceolata* (Lamb.) Hook.) in Sanming, Fujian. The results showed that N, P concentration of Chinese fir and Tsoong's tree in fine roots were negatively related to root diameter size. The concentrations of N and P in living roots and dead roots were compared. The order of N concentration in fine roots in different samples was Tsoong's tree >undergrowth >Chinese fir, while that of P was undergrowth > Tsoong's tree > Chinese fir. For Chinese fir, the seasonal change of N, P concentrations in fine roots with various diameter classes showed a single-apex curve with a maximum in September. For Tsoong's tree, maximized concentration of N in fine roots appeared in July or September and maximized P concentration in May.

Key words: Fine root; Chinese fir; Tsoong's tree; Mixed forest; Nitrogen; Phosphorus

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Introduction

Fine roots are an important source in terrestrial ecosystems. Plants depend on fine roots (<2mm in diameter) for water and mineral. The primary net production belowground can be greater than that of aboveground organs (e.g., Nadelhoffer *et al.* 1985). In many cases of studies, fine roots have higher nutrient concentrations (e.g., Meier *et al.* 1985) and shorter life-spans than foliages (Vogt *et al.* 1983). Nutrient released from decomposing roots is an important pathway of nutrient flux in terrestrial ecosystems (Joslin *et al.* 1987; Fahey *et al.* 1988). In forests, for example, the amount of carbon and nutrients in the soil from fine roots may equal or exceed that from leaf litter (Joslin *et al.* 1987; Raich *et al.* 1989).

In the relatively short life-spans of fine roots, the dynamics of nutrient concentration in fine roots is important in estimating nutrient cycling relationship between fine root diameter classes and nutrient contents. In this paper, we examined the difference of nutrient concentration contents in fine roots among conifer, broadleaved and undergrowth, and the relationship between nutrient content and fine root diameter classes.

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Sites

The study sites are located in Xiaohu experimental area of Xinkou Experimental Forestry Farm of Fujian Agricultural and Forestry University, Sanming, Fujian Province (26°11′30″N, 117°26′00″E). This area has a sub-tropical monsoonal climate with an annual mean temperature of 19.1℃, an annual precipitation of 1 749 mm, an annual mean transpiration of 1 585.0 mm, an annual relative humidity of 81%, and a frost-free period of around 300 d. The soil is red soil derived from sand-sale. The mixed forest of Chinese fir (*Cunninghamia lanceolata* (Lamb.) Hook.) and Tsoong's tree (*Tsoongiodendron odorum* Chun) was established with seedling in 1973 with a planting density of 3 000 stems per hectare. The mixed pattern is strip spacing, with three rows of Chinese fir spaced by one row of Tsoong's tree. At the time of survey (at age 27), Chinese fir had a density of 907 stems per hectare and Tsoong's tree for 450 stems per hectare. The mean tree height and D.B.H (diameter at breast height) were 20.88 m and 25.1 cm for Chinese fir, and 17.81 m and 17.0 cm for Tsoong's tree, respectively. The crown density was of 0.95 and the undergrowth coverage was of 80%.

Methods

From September 1999 to July 2000, 30 soil cores were collected at random to a depth of 100 cm within different samples (Chinese fir, Tsoong's tree and undergrowth) at bimonthly intervals using a steel core (6.8 cm in inner diameter, 120 cm in length). Soil samples were washed in tap water to remove adhering soil and accompanying organic debris, then the roots of object trees and undergrowth were

detached with the help of magnifying glass, scissors and tweezers, etc.. At the same time fine roots (<2mm in diameter) were picked up, and separated into live and dead categories according to their respective appearance, color, flexibility and the cohesion between cortex and periderm. The fine roots of object trees were further sorted into three diameter classes (1-2 mm, 0.5-1 mm, <0.5 mm). All the roots were oven-dried (80℃) and weighed. The standing crops of fine roots were calculated using the following formula:

$$C=W \times 100/(\pi(6.8/2)^2)$$

Where:

C--the standing crop of fine roots ($t \cdot hm^{-2}$);

W--dry weight of fine roots per core (g).

Root samples for nutrient analysis were oven-dried. For the determination of N, root samples were digested in $K_2Cr_2O_7$-H_2SO_4 solution and then N was determined by micro-Kjeldahl technique. Samples for P analysis were in a mixture of HNO_3, H_2SO_4 and $HClO_4$ solution, and concentration of P was analyzed by a Molybdenum blue colorimetrical procedure (Department of Science and Technology of the Ministry of Forestry 1991).

Results and discussion

Concentrations of N and P in the fine roots

There was a significant inverse relationship between root diameter and nutrient concentration for N and P examined. The mean nutrient concentration in both live and dead roots decreased significantly among root diameters of<0.5 mm, 0.5-1 mm and 1-2 mm (P<0.001). A strong decline in the concentrations of N and P with an increase in diameter classes of fine roots has also been found in an *Abies amabilis* stand (Vogt *et al.* 1983), in a range of hardwood and pine forests (McClaugherty *et al.* 1982), in Douglas-fir for N, P, K, Ca and Mg (Fogel *et al.* 1983), and in *Pinus radiata* for N, P and Ca (Nambiar 1987). Nambiar (1987) had reported that concentration of N decreased by 26% as the root diameter of *Pinus radiata* increased from <0.5 mm to 0.5-1.0 mm, and increased by 83% when root diameter was >5 mm.

Comparison of live and dead roots of various diameter classes showed that nutrient was likely to retransfer, but the amount of nutrient transfer was somewhat small. The differences in nutrient concentration between living and dead roots were insignificant (P<0.03) and differences in mean concentration were less than 10% (Table 1). It was in line with other reports that only a small amount of nutrients was transferred out from the senesced fine roots (McClaugherty *et al.* 1982; Nadelhoffer *et al.* 1985).

Nutrient concentration in fine roots (<2mm in diameter) differed significantly among three samples (P<0.001). The mean N concentration showed a tendency of Tsoong's tree > undergrowth > Chinese fir. And P concentration showed a tendency of undergrowth >Tsoong's tree >Chinese fir. It seemed that there was a sense of cooperation among undergrowth, *T. odorum* and *Cunninghamia lanceolata* in utilization of N and P, which is advantageous to make full use of nutrients in mixed forest.

Table 1. The concentrations of N and P in fine roots in the mixed forests ($g \cdot kg^{-1}$)

Species	Fine roots	Root diameter							
		1-2 mm		0.5-1 mm		<0.5 mm		<2 mm	
		N	P	N	P	N	P	N	P
Chinese fir	Living	5.748	0.335	6.875	0.410	9.189	0.548	8.009	0.476
	Dead	5.435	0.306	6.488	0.383	9.100	0.537	7.965	0.467
	Average	5.664	0.327	6.770	0.403	9.161	0.545	7.996	0.474
Tsoong's tree	Living	7.718	0.857	10.846	0.973	15.568	1.355	13.376	1.207
	Dead	7.255	0.744	10.487	0.843	13.805	1.143	11.726	1.004
	Average	7.571	0.823	10.738	0.932	15.119	1.301	12.924	1.151
	Tree layer	7.083	0.502	9.093	0.581	12.518	0.834	10.753	0.719
Undergrowth	Living							9.432	1.938
	Dead							9.226	1.732
	Average							9.387	1.865
	Community							8.698	0.763

Seasonal change in concentration of N and P in fine roots of mixed forest

The monthly change in concentration of N and P in fine roots of various diameter classes for Chinese fir was similar, showing a single-apex curve during the whole year (Fig. 1, 2). The nutrient concentration was low in March, then rose gradually and reached a maximum in September, at last declined again thereafter. This seasonal trend was related to the growth pattern of Chinese fir and the change of climate in a year. The lower nutrient concentration in winter was due to the cease of root activity and furthers the suspension of nutrient absorption. In early spring (March), the minimum nutrient concentration was largely due to the dilution of nutrients by a large quantity of new roots. In summer, the increased nutrient concentration was related to the increase in root activity, nutrient absorption and nutrient accumulation, and then maximum nutrient concentration of fine roots in autumn.

The seasonal change of N and P concentration in fine roots of Tsoong's tree showed similar single-apex curves, N concentration peaked in July and that of P reached a

maximum in May (Fig. 3, 4). The time of maximum concentrations of N or P for Tsoong's tree was prior to that of Chinese fir. This difference may be largely contributed to the differences in biological properties or superiority in competition for nutrients between the two species. On the one hand, the time of initial nutrient absorption and maximum nutrient concentration for Tsoong's tree roots was earlier than that of Chinese fir roots. On the other hand, the roots of Tsoong's tree got inferior position in competition for nutrients with roots of Chinese fir; thus, roots of Tsoong's tree were suppressed when roots of Chinese fir speeded up their nutrient absorption.

The seasonal trend for concentrations of N and P in fine roots of undergrowth was similar to those of Tsoong's tree, concentration of N peaked in July and that of P peaked in May (Fig. 5, 6).

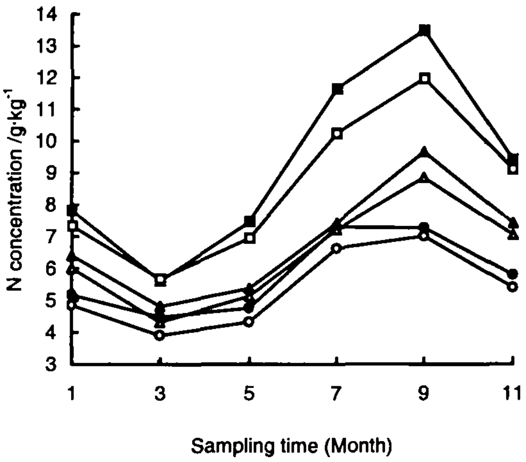

Fig. 1 Seasonal change of N concentration in fine roots of Chinese fir in mixed forest

-▲- dead root diameter of 0.5-1 mm; -△- living root diameter of 0.5-1 mm; -□- living root diameter of <0.5 mm; -●- dead root diameter of 1-2 mm; -○- living root diameter of 1-2 mm; -■- dead root diameter of <0.5 mm

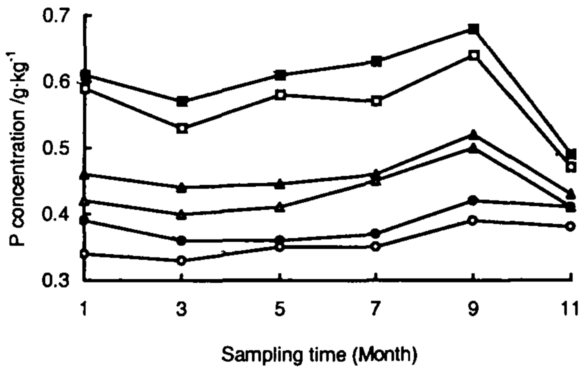

Fig. 2 Seasonal change of P concentration in fine roots of Chinese fir in mixed forest

-▲- dead root diameter of 0.5-1 mm; -△- living root diameter of 0.5-1 mm; -□- living root diameter of <0.5 mm; -●- dead root diameter of 1-2 mm; -○- living root diameter of 1-2 mm; -■- dead root diameter of <0.5 mm

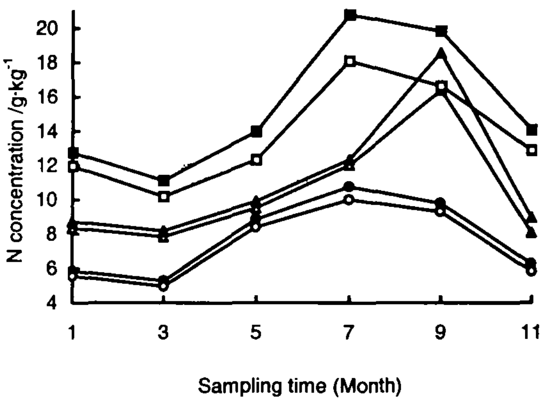

Fig. 3 Seasonal change of N concentration in fine roots of Tsoong's tree in mixed forest

-▲- dead root diameter of 0.5-1 mm; -△- living root diameter of 0.5-1 mm; -□- living root diameter of <0.5 mm; -●- dead root diameter of 1-2 mm; -○- living root diameter of 1-2 mm; -■- dead root diameter of <0.5 mm

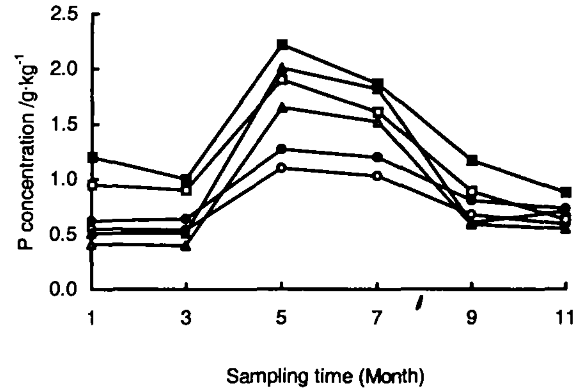

Fig. 4 Seasonal change of P concentration in fine roots of Tsoong's tree in mixed forest

-▲- dead root diameter of 0.5-1 mm; -△- living root diameter of 0.5-1 mm; -□- living root diameter of <0.5 mm); -●- dead root diameter of 1-2 mm; -○- living root diameter of 1-2 mm; -■- dead root diameter of <0.5 mm

Detailed reports on the seasonal change in nutrients of fine roots in forests are rare. McClaugherty *et al.* (1982) reported that in a mixed hardwood forest and red pine plantation, although N percentage showed some seasonal pattern, these fluctuations were small and not significant. In a *Picea sitchensis* plantation, N concentration in live roots with <1mm in diameter showed relatively small seasonal fluctuations, and it was suggested that the fluctuations may represent redistribution within roots or accumulation of nitrogen compounds in winter (Alexander, 1985). Nambiar (1987) reported that there was no evidence of a seasonal pattern in roots nutrient concentration of *Pinus radiata*. The

discordance in results might result from the differences in tree characteristics and climate conditions.

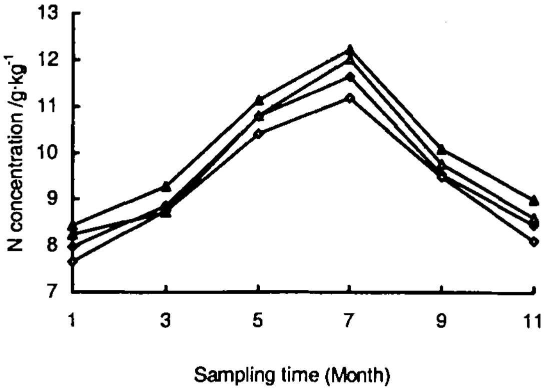

Fig. 5 Seasonal change of N concentration in fine roots of undergrowth

-◇-Mixed forest; -◆- Mixed forest; -▲-pure forest; -△- pure forest

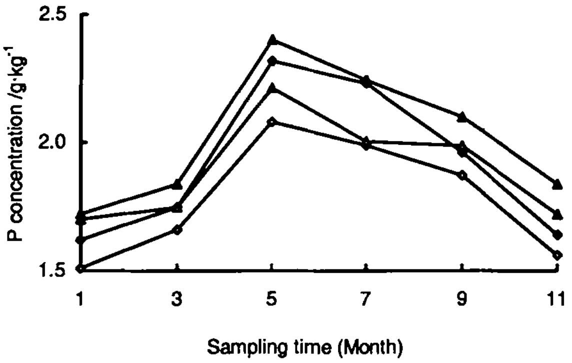

Fig. 6 Seasonal change of P concentration in fine roots of undergrowth

-◇-Mixed forest; -◆- Mixed forest; -▲-pure forest; -△- pure forest

Conclusions

In the mixed forest of Chinese fir and Tsoong's tree, the order of N concentration in fine roots of various components was Tsoong's tree >undergrowth >Chinese fir, while that of P was undergrowth >Tsoong's tree > Chinese fir. It seemed that there was one sense of cooperation between Tsoong's tree and undergrowth in utilization of N and P. For Chinese fir, seasonal change of N, P concentrations in fine roots of various diameter classes showed a single-apex curve with a maximum in September. For Tsoong's tree, maximized concentration of N in fine roots appeared in July or September and maximized P concentration in May.

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